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Tenax-GC Cartridge for Interfacing Capillary Column Gas Chromatography with Adsorption/Thermal Desorption for Determination of Trace Organics

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16. ABSTRACT

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An interface which allows the thermal desorption of large (~5 cm^3) Tenax-GC cartridges to fused silica capillary gas chromatography columns has been developed and tested. The interface makes use of a small Tenax-GC cartridge for intermediate trapping and a secondary thermal desorption at 270°C with a carrier flow rate of 2.5 mL/min to transfer the analytes to the subambient column. The determination of several nonpolar aqueous organic compounds including o-dichlorobenzene, 1,2,4-trichlorobenzene, and naphthalene at the ng/L level with ± 2% precision is demonstrated. The values obtained for several column performance criteria including resolution (ethylbenzene/p-xylene and 1-octadecene/n-octadecane), two Trennzahl numbers (octane/decane and elcosane/henelcosane), three peak asymmetry factors (5-nonanone, acetophenone, and 1-tetradecanol), and the system acidity and bacity compare very favorably with the performance specifications which have been proposed in the literature for those parameters, as well as the values obtained by splitless injection.

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Tenax-GC Cartridge for Interfacing Capillary Column Gas Chromatography with Adsorption/Thermal Desorption for Determination of Trace Organics

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An interface which allows the thermal desorption of large (~5 cm^3) Tenax-GC cartridges to fused silica capillary gas chromatography columns has been developed and tested. The interface makes use of a small Tenax-GC cartridge for intermediate trapping and a secondary thermal desorption at 270 °C with a carrier flow rate of 2.5 mL/min to transfer the analytes to the subambient column. The determination of several nonpolar aqueous organic compounds including *o*-dichlorobenzene, 1,2,4-trichlorobenzene, and naphthalene at the ng/L level with ±2% precision is demonstrated. The values obtained for several column performance criteria including resolution (ethylbenzene/*p*-xylene and 1-octadecene/*n*-octadecane), two Trennzahl numbers (octane/decane and eicosane/heneicosane), three peak asymmetry factors (5-nonanone, acetophenone, and 1-tetradecanol), and the system acidity and basicity compare very favorably with the performance specifications which have been proposed in the literature for those parameters, as well as the values obtained by splitless injection.

A number of different concentration methods are available for aqueous organics. They include purge and trap (*1*), "Grob stripping" (*2*), solvent extraction (*3*), and adsorption onto sorbents such as the Amberlite XAD resins followed by solvent extraction (*4*). Adsorption from aqueous solution onto a polymeric sorbent followed by thermal desorption (ATD) has received limited attention in the past with the XAD sorbents (*5–7*) and Tenax-GC (*8–12*). Our initial work with Tenax-GC indicated that the three United States Environmental Protection Agency (U.S. EPA) "priority pollutants" *p*-dichlorobenzene, hexachloro-1,3-butadiene, and 2-chloronaphthalene are retained at the 74–90% level when μg/L solutions are passed at 1 mL/s through a cartridge with a bed length and inside diameter of 7.0 and 0.94 cm, respectively (0.75 g, 35/60 mesh) (*12*). The analytes were thermally desorbed to the head of a packed gas chromatography (GC) column, whereupon the determination by GC was carried out. If the applicability of ATD with Tenax-GC is to be extended to the analysis of environmental water samples, it should be interfaced with capillary GC.

A major problem with the desorption of a Tenax-GC cartridge of the above dimensions directly onto a capillary column is that flow rates of ~30 mL/min (15 min total desorption time) are required for the desorption, and capillary column flow rates are typically only ~1–2 mL/min. One way to deal with this flow mismatch is to insert a trapping interface between the main desorption device and the capillary column. The interface should remove the analytes from the desorption carrier gas at flow rates of ~30 mL/min, and it should later transfer them to the capillary column at flow rates of ~2 mL/min.

This problem has been faced by other workers and two main types of interfaces have emerged which meet the above criteria. The first type, developed for purge and trap analysis, involves the passage of the main desorption effluent through a nickel capillary trap cooled with liquid nitrogen. (In one version, the capillary is 0.9 m long with a 1.0 mm i.d. (*13*).) With the GC column at ambient temperatures, the trap is then heated ballistically, thereby transferring the analytes to the column. The chromatographic determination follows immediately.

In the second approach, the trap is a small, fixed cartridge of a polymer sorbent material, usually Tenax-GC (*6, 7*). After the main desorption is complete, the interface cartridge is heated. The sorbed compounds will be released over a range of temperatures and therefore over a finite period of time. For good chromatographic resolution to be preserved, however, the analytes must be placed in a narrow band at the head of the column. If one is dealing with reasonably volatile compounds, it is reportedly possible to heat the cartridge quickly enough that peak sharpness is retained (*14*). A second method is to isolate the sorbent trap until the temperature is reached at which all of the target analytes become mobile. A valve is then opened and the analytes are transferred to the column (*6, 7*). A disadvantage of this method is that as the interface trap is heating, the volatilized, stagnant analytes will have good opportunity to react with whatever active sites there may be in that section of the system. Secondly, since relatively large carrier gas flows will still be required to flush the trap, the valve, and the transfer line, the only way to place the analytes on the column in a spike manner is to split off the majority of the flow (Ryan used a split ratio of 10:1 (*7*)) as the transfer valve is opened. The result is a loss of sensitivity and the potential for volatility discrimination. A third method of maintaining peak sharpness is to cool the front section of the column as the cartridge is heated. Such cold trapping has been used successfully when desorbing small Tenax-GC cartridges directly to capillary columns in the purge and trap analysis of water samples (*15, 16*) and in the analysis of small Tenax-GC atmospheric sampling cartridges (*17–19*).

Our interface between ATD and capillary GC employs a small, fixed Tenax-GC interface cartridge designed in a manner such that 100% of the flow passes to the capillary column. During the desorption, the column is maintained at subambient (−30 °C) temperatures to trap the analytes at the head of the column. An additional important feature of this interface is its use of a short piece of small inside diameter (0.50 mm) glass-lined stainless steel tubing as the interconnect to the fused silica capillary column. It provides a slightly larger bore immediately prior to the column. During the desorption, if small amounts (<1 μL) of water remain in the system, this water will freeze in the tubing and not plug the smaller inside diameter column.

EXPERIMENTAL SECTION

Sample Cartridge Preparation. The sample cartridges were of Pyrex glass. The bed length and inside diameter were 6.0 and 0.69 cm, respectively. The bed volume was 2.2 cm^3. The outside diameter of a cartridge main body was 0.90 cm. A 1.5 cm long

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piece of 2.0 mm i.d., 0.64 cm (0.25 in.) o.d. glass tubing was fused to each end of this main body. The cartridges were packed with approximately 0.38 g of 35/60 mesh Tenax-GC obtained from Alltech Associates, Inc. (Los Altos, CA). The Tenax-GC was held in place with silanized glass wool (Supelco, Inc., Bellefonte, PA). (We did not silanize the glass cartridges since some water does persist on the cartridges up to the time of desorption (*12*), and glass-bound silyl groups will hydrolyze in the presence of water at the anticipated desorption temperatures (*20*).) After a cartridge was packed, it was conditioned for 60 min at 280 °C with 30 mL/min flow of precleaned N_2. (Although not employed in this study, the passage of a large number of bed volumes of solvents such as methanol and pentane (*21*) and acetone through the cartridges prior to the thermal conditioning step is very helpful in lowering overall blank levels.)

Interface Cartridge Preparation. The interface cartridge was of Pyrex glass. The bed length and inside diameter were 5.0 and 0.40 cm, respectively. A 4.1 cm piece of 2.0 mm i.d., 6.4 mm (0.25 in.) o.d. glass tubing was fused to the upper end of the main bed. A 3.8 cm piece of the same glass (with a slight constriction in the middle to help immobilize the sorbent) was fused to the lower end. The cartridge was packed with 0.12 g of 35/60 mesh Tenax-GC. Silanized glass wool was used to keep the Tenax-GC in place. The glass cartridge was not silanized. Thermal conditioning was carried out as with the sample cartridges.

Sample Cartridge Loading. "Standard cartridges" were loaded by injecting 2–4 μL of an acetone standard into the bed of a sample cartridge. "Zero water" was prepared by simultaneously boiling and sparging (1 h) water obtained from a Millipore (Bedford, MA) Super Q (ion exchange/carbon adsorption) system. The apparatus in the recovery tests represents a water analogue of a device (*22*) used to load Tenax-GC cartridges with gas-phase organics. Briefly, the apparatus consists of a reservoir for zero water, an injection port, a cartridge packed with glass wool (for good mixing), the sample cartridge, and finally a stopcock which is used to meter the flow. Gases occupying the void volume of a cartridge were first removed by setting a peristaltic pump (attached to the stopcock) at a flow rate of ~4–5 mL/s for 1 min. The pump was then removed, the reservoir pressurized slightly (3–4 psi), and the flow set at 0.5 mL/s with the stopcock. Four microliters of the recovery standard in acetone (25 μg/μL per component) was then injected. After 1 L of water was passed, the sample cartridge was removed and desiccated. Other details concerning the apparatus are provided elsewhere (*12*).

Sample Cartridge Desiccation. A two-step procedure was used to desiccate all sample cartridges. The first step involved a 10-min centrifugation at 3500 rpm. A 10-min evacuation was the second step. This procedure reduces the residual water on a sample cartridge of this size to approximately 2 μL. Further details may be found elsewhere (*12*).

Sample Cartridge Desorption. Following desiccation, the desorption of all sample cartridges was carried out in the apparatus (referred to here as the "sample desorption apparatus") developed in our laboratory. (A schematic diagram of this apparatus may be found in Figure 4 of ref 12.) In this work, the interface cartridge was substituted for the packed column used earlier. The desorption carrier gas left the interface cartridge at ambient temperatures. The initial O_2 purge time (to avoid oxidative decomposition), the desorption time and temperature, and the He carrier flow rate were 15 min, 15 min, 280 °C, and 30 mL/min, respectively. This desorption step provided an additional degree of desiccation for the system, since at ambient temperatures 450 mL of carrier gas (15 min × 30 mL/min) can remove as much as 4.4×10^{-4} mol of water, or the equivalent of 7.9 μL of liquid water.

Interface. The interface cartridge butted up against the main sample cartridge and was held in the GC oven with a 6.4 mm i.d. graphite–vespel ferrule (Alltech Assoc.) in a Swagelok nut (Figure 1). The dimensions of the aluminum heater block were 1.8 × 2.7 × 5.5 cm. A 6.4-mm hole was drilled through for the interface cartridge. A well for an iron–constantan thermocouple was provided, as was a 5.1 cm deep × 0.9 cm i.d. well for a 100-W cartridge heater (Watlow, Inc., St. Louis, MO). The extra-long $^1/_4$ in. × $^1/_{16}$ in. reducing union at the lower end of the interface cartridge was fabricated by silver soldering together sections of two stainless steel Swagelok tubing connectors. An aluminum heating block (1.0 × 1.5 × 5.5 cm) powered by an 80-W cartridge heater (Watlow, Inc.) was secured to the brass union. The 80-W and the 100-W cartridge heaters were connected in parallel.

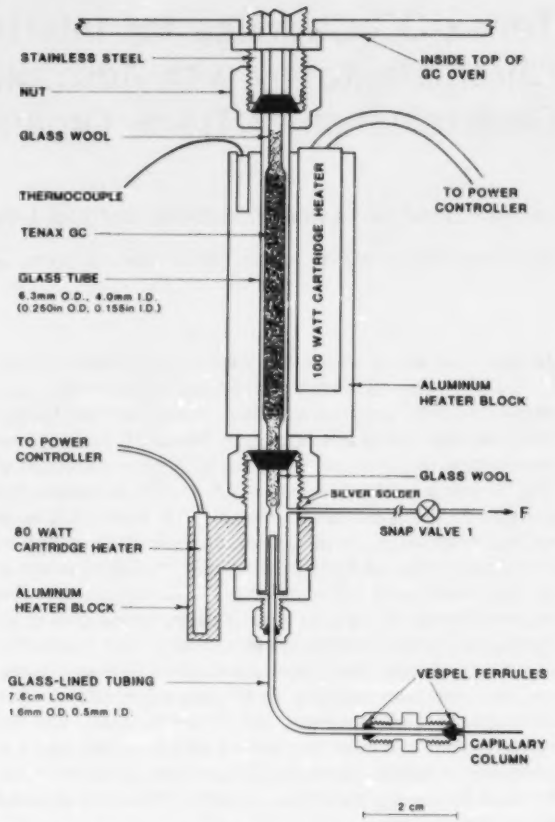

Figure 1. ATD/capillary gas chromatography interface.

The ice trap, a 7.6 cm long, $^1/_{16}$ in. (1.6 mm) o.d. piece of 0.50 mm i.d. glass-lined stainless steel tubing (Scientific Glass Engineering, North Melbourne, Australia) was inserted 2.5 cm into the union. The tubing extended ~1.2 cm into the lower end of the interface cartridge. Prior to its installation, the glass surfaces of the tubing were deactivated by a method originally suggested by de Nijs et al. (*23*). A 6.4 mm o.d. glass tube packed with 30% Carbowax 20M on Chromosorb W was placed in a GC injection port heated at ~250 °C. The glass tube extended into the GC oven. A $^1/_4$ in. × $^1/_{16}$ in. Swagelok union was used to connect the glass-lined tubing. The flow was set at 3 mL/min and the GC oven temperature run up to 220 °C. The conditioning period was 2 h. Vapors bleeding from the injector encountered a cooler temperature in the tubing. The resultant condensation of the Carbowax 20M vapors served to deactivate the glass surface.

Interface Cartridge Desorption. During the purge of O_2 from the sample cartridge and during its desorption, the majority of the He carrier exited through a needle valve on line F (Figure 1). A small portion passed through the column. Immediately after the sample cartridge desorption, a snap valve on line F was closed, as was a snap valve on gas line A (see Figure 4 of ref 12). With the carrier gas pressure set at 20 psi, a snap valve on gas line E was then opened (see Figure 4 of ref 12). This resulted in a pressure of 19 psi at line F, and linear and volume flow rates through the column of 46 cm/s and 2.5 mL/min, respectively. The GC oven was then cooled to −30 °C with liquid nitrogen, at which point the oven fan was turned off and power provided to the two cartridge heaters (leaving the fan on would slow the heating of the interface). The oven temperature was maintained at −30 °C during the entire desorption. The block temperature was monitored with an iron–constantan thermocouple. Power to the cartridge heaters was discontinued approximately 4.5 min after its initial application when the temperature in the upper and lower blocks reached 260 and 255 °C, respectively. The temperature in the upper block maximized at 270 °C and dropped

to 140 °C approximately 15.5 min after power was first applied. At this point the oven fan was activated and the GC temperature program was started.

Gas Chromatography. The top of a Model 5700 Hewlett-Packard (Avondale, PA) gas chromatograph was modified to accept the sample desorption apparatus (*12*), and the capillary interface was connected as described above. A new 30 m long, 0.25 mm i.d., 0.25 μm film thickness DB-5 (SE-54) fused silica capillary column obtained from J&W Scientific (Rancho Cordova, CA) was connected to the glass-lined steel tubing of the interface with a $^1/_{16}$ in. × $^1/_{16}$ in. brass Swagelok tubing union drilled out to $^1/_{16}$ in. The column extended 0.5 mm out of the 100% vespel ferrule (Alltech Associates). The glass-lined tubing was butted up against the ferrule to minimize dead volume and exposure to the vespel. As mentioned above, the helium carrier gas linear velocity during analyses on the HP-5700 was 46 cm/s. The H_2, N_2 make-up, and air flow rates at the flame ionization detector were 30, 20, and 240 mL/min, respectively. The detector temperature was 300 °C. The temperature program used on the HP-5700 was −30 to 50 °C ballistically and then 50 to 250 °C at 4 °C/min. Peak areas and retention times were determined with a Spectra-Physics (Santa Clara, CA) 4100 computing integrator.

Analyses of the column performance standard were carried out on the ATD system on the HP-5700 and for comparison by injection on an HP-5880A capillary GC. The HP-5880A helium carrier gas linear velocity was 35 cm/s. The H_2, He make-up, and air flow rates at the flame ionization detector were 30, 25, and 425 mL/min, respectively. The septum sweep and injector split flow rates were set at 5 and 60 mL/min, respectively. Injections were made in a splitless manner with the split valve opening after 36 s. The injector and detector temperatures were 250 °C and 325 °C, respectively. The temperature program was 45 to 250 °C at 4 °C/min.

The HP-5880A was also used to determine the extra-column broadening caused by a piece of tubing similar to that used to connect the interface to the column. Short sections of stainless steel tubing of varying lengths and inside diameter were spliced into the column immediately after the injector using two of the same type of drilled-out $^1/_{16}$ × $^1/_{16}$ in. Swagelok union and ferrule assembly as described for connecting the interface to the column. Methane was injected in the split mode of operation and the standard deviation of the resulting peak was measured at 0.61 of peak height on the leading side of the near-Gaussian peak.

Cartridges which were loaded for the determination of percent recoveries were analyzed with a Finnigan 4000 gas chromatograph mass spectrometer/data system (GC/MS/DS) (Finnigan Instruments, Sunnyvale, CA). For these analyses, the desorptive transfer of analytes from a main sample cartridge to an interface cartridge was carried out on the apparatus mounted on the HP-5700. The interface was then removed, and 4 μL of a 2-bromo-*m*-xylene internal standard in acetone (5 ng/μL) was added by syringe directly to the interface cartridge. The interface was then transferred to the Finnigan 4000 where the upper end was connected to the capillary injector. The desorption of the interface was carried out as when the system was mounted in the HP-5700. (If the sample desorption apparatus had been mounted on the GC of the Finnigan 4000, the internal standard would have been added directly to the sample cartridge.)

The type of capillary column used in the Finnigan 4000 was identical with that employed in the HP-5700. The column was passed through the capillary transfer line where it ended 5 mm from the source. The transfer line, source, and MS manifold temperatures were maintained at 220, 250, and 100 °C, respectively. The helium linear flow rate in the column was 25 cm/s, and the temperature program was 30–50 °C ballistically and then 50–200 °C at 10 °C/min.

System Performance Evaluation Solution. Several compounds were selected from the components present in the chromatographic system performance evaluation solutions (SPES) suggested by Grob (*24*) and employed in the Master Analytical Scheme (MAS) Interim Protocols for the analysis of organic purgeables and base/neutrals (*25*). A 10 ng/μL per component solution was prepared in acetone and 2 μL volumes were injected onto a sample cartridge and analyzed using the ATD apparatus. This standard was also analyzed by splitless injection on the HP 5880A.

Table I. Variance of Methane Peak Resulting from Total Dispersion in the Gas Chromatograph Both with and without Tubing Spliced in Column

tube i.d., mm	tube length, cm	variance σ^2 of methane peak,[a] s^2
no tube	0.0	0.328
0.76	5.1	1.103
0.76	7.6	1.407
0.76	10.2	1.626
0.46	7.6	0.419

[a] Average of three measurements

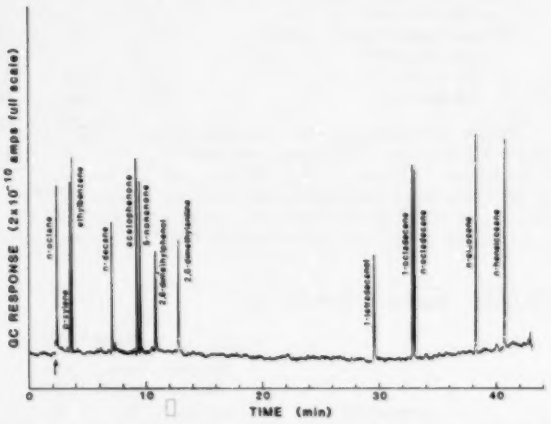

Figure 2. Gas chromatogram of system performance evaluation standard run using interface between ATD sample desorption apparatus and a 30 m × 0.25 mm i.d. SE-54 fused silica capillary column.

RESULTS AND DISCUSSION

Dispersion in Connecting Tube. It is well recognized that the dispersion which occurs in connecting tubes may be minimized by using short sections of small inside diameter tubing. The results of the dispersion measurements for several different pieces of tubing are presented in Table I. The three data points for the 0.76-mm tubing are approximately linear as expected. The intercept A for the line $\sigma^2 = A + Bl$ where l is the length of 0.76 mm i.d. tubing in cm is about 0.540 s^2. Thus, (0.540 s^2 − 0.328 s^2) = 0.212 s^2 may be associated with the dispersion occurring at the ends of the fittings. B is approximately 0.12 s^2/cm. Sternberg (*26*) has presented theoretical expressions for B and also discusses the dispersion expected in fittings. Scott (*27*) has measured the magnitudes of these effects for microbore liquid chromatography systems.

In our system, a 5.1 cm piece of 0.76 mm i.d. tubing markedly increases the total variance above the 0.328 s^2 observed with no tubing. In contrast, a 7.6 cm piece of 0.46 mm i.d. tubing degrades the system performance much less. These experiments provided the rationale for the selection of the dimensions of the ice trap between the interface cartridge and the capillary column.

System Performance Evaluation. Table II presents the results obtained for analyses of the SPES by the ATD system on the HP-5700 and by splitless injection on the HP-5880A. Figure 2 is a chromatogram of 2 μL of the standard placed on a sample cartridge and analyzed on the ATD interface system. For clarity, the portion of the chromatogram containing peaks due to trace impurities in the acetone solvent has been deleted by shunting the signal from the integrator up to the point indicated by the arrow. The quantitative parameters which have been calculated for this system compare very favorably to the specifications set in the MAS (*22*), as do those obtained by splitless injection on the HP-5880A.

Table II. System Purgeable (P-) and Base/Neutral (BN-) Performance Parameters[a]

P- or BN- performance parameter	ATD interface (HP-5700)				splitless injection (HP-5880A)				MAS specification (16)
				mean				mean	
P-resolution ethylbenzene/*p*-xylene	2.4	2.8	3.3	2.8	2.2	2.4	2.0	2.2	>1.0
BN-resolution 1-octadecene/*n*-octadecane	99	99	99	99	100	99	100	100	>50% valley
P-Trennzahl no. octane/decane	49	60	56	58	47	53	55	52	>50
BN-Trennzahl no. eicosane/heneicosane	20	19	23	21	18	18	18	18	>10
P-peak asymmetry factor 5-nonanone	87	69	78	78	107	101	109	106	<160
P-, BN-peak asymmetry factor acetophenone	62	70	51	61	119	116	119	118	<300
BN-peak asymmetry factor 1-tetradecanol	119	121	120	120	108	118	113	113	<250
P-, BN-acidity	1.1	1.2	1.2	1.2	1.0	1.0	1.0	1.0	0.7–1.3
P-, BN-basicity	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.7–1.3

[a] Values obtained for three analyses using the ATD interface on the HP-5700 and for three analyses by splitless injection on the HP-5880A. The same, new fused silica column was used on both instruments. Performance parameter definitions: P-resolution = $2D/(W_1 + W_2)$; BN-resolution = % valley; Trennzahl no. = $D/(w_1 + w_2) - 1$; PAF = $B/F \times 100$; acidity = (area/μg DMP)/(area/μg acetophenone); basicity = (area/μg DMA)/(area/μg acetophenone). D = distance between two peaks, w = peak width at 0.5 peak height, W = peak width at base, B = width of back half of peak at 0.1 peak height, and F = width of front half of peak at 0.1 peak height; DMP = 2,6-dimethylphenol, DMA = 2,6-dimethylaniline.

Table III. Recovery Efficiencies

compound	quantitation ion *m/z*	% recovery run ATD 10	% recovery run ATD 16
o-dichlorobenzene	146	81	79
hexachloroethane	201	62	75
1,2,4-trichlorobenzene	180	83	83
naphthalene	128	81	81
hexachloro-1,3-butadiene	225	85	78
2-chloronaphthalene	162	92	90
2-bromo-*m*-xylene (int std)	105		

It is interesting to note that the peak asymmetry factor (PAF) values for 5-nonanone and acetophenone were less than 100 with the ATD system but greater than 100 on the HP-5800A with the exact same column. The slight overloading (PAF ≃ 60–90) observed by ATD on the HP-5700 at the 20 ng/component level for these compounds was therefore not the result of a poor coating on this new column. Rather, it may have been the result of a reduction of the effective capacity of the methyl silicone coating at the low temperatures used during the desorption, and the absence of a peak sharpening solvent effect. If a 60-m rather than a 30-m column had been used, it is likely that these peaks would have regained their symmetry.

The excellent peak symmetry which we obtained with 1-tetradecanol demonstrates (1) the greater capacity of the column for compounds with volatilities lower than that of acetopenone or 5-nonanone and (2) the effectiveness of the vapor-phase Carbowax procedure used to deactivate the glass-lined tubing. The deactivation procedure contributed substantially to the success of this interface inasmuch as untreated stainless steel tubing, untreated glass-lined tubing, and glass-lined tubing treated with a 1% wt/wt solution of Carbowax 1000 all failed to give PAF, acidity, and basicity values even close to the MAS specifications.

Recovery Efficiencies. The overall recovery efficiencies for two replicate runs are presented in Table III. The reproducibility is quite good for determinations at the ng/L level. Except for hexachloroethane which displayed slightly lower recoveries, the results are in the 80–90% range. Similar recoveries were obtained with *p*-dichlorobenzene, hexachloro-1,3-butadiene, and 2-chloronaphthalene in our earlier study (*12*). The cartridge dimensions and volume flow rates employed in that study were similar to those used in this work.

CONCLUSIONS

The capabilities of ATD with Tenax-GC in the determination of trace aqueous organics have been extended considerably through the development of this interface. The fact that virtually 100% of the analyte compounds may be placed on-column provides this methodology with unparalleled sensitivity for the analysis of water samples. While the method detection limits (MDLs) for this procedure have not been determined, approximate estimates may be obtained by comparison with MDL values determined by Olynyk et al. (*28*) for EPA Method 625 as employed with packed columns and 35–350 amu scanning MS detection. (These and other MDL values are tabulated by Glaser et al. (*29*).)

According to Method 625, a 1-L sample is serially extracted and the solvent volume is reduced to 1.0 mL. A volume on the order of 2 μL is injected. This corresponds to 0.2% of the original analytes. For relatively clean "reagent water" as the sample matrix, Olynyk et al. (*28*) report that the compounds in Table III all have MDL values in the 0.9–1.9 μg/L range.

Assuming that the background levels are not substantially higher by the ATD method, these data imply that ATD with Tenax-GC would provide MDL values in the 1.8–3.8 ng/L range for packed column work since 100% of the analytes in the 1-L sample would be passed to the column. An additional improvement of at least 1 order of magnitude may be expected when interfacing to capillary GC occurs, bringing the MDL values down by an overall factor of ~2000.

Since the interface described in this paper meets the MAS specifications as well as is achieved by splitless injection, it is apparent that the chromatography will not be a limiting factor in the application of this method to the types of compounds given in Table III. Aqueous ATD (with Tenax-GC) interfaced to capillary GC provides both preconcentration ease and method sensitivity in the determination of such compounds.

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